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Research Article

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New atlas of open star clusters

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Abstract: Due to numerous new discoveries of open star clusters in the last two decades, astronomers need an easy-to-use resource to get visual information on the relative position of clusters in the sky. Therefore we propose a new atlas of open star clusters. It is based on a table compiled from the largest modern cluster catalogues. The atlas shows the positions and sizes of 3291 clusters and associations, and consists of two parts. The first contains 108 maps of 12 by 12 degrees with an overlapping of 2 degrees in three strips along the Galactic equator. The second one is an online web application, which shows a square field of an arbitrary size, either in equatorial coordinates or in galactic coordinates by request. The atlas is proposed for the sampling of clusters and cluster stars for further investigation. Another use is the identification of clusters among overdensities in stellar density maps or among stellar groups in images of the sky.

Keywords: open clusters and associations: general

1 Introduction

Open star clusters (OCls) are very important objects for astrophysics. It is well known that theories of stellar evolution are verified by star cluster colour-magnitude diagrams. OCLs show us the history of star formation in the Galactic disk, with young clusters being tracers of the Galactic spiral structure. Star clusters serve as laboratories for further stellar dynamics studies. The scientific interest in star clusters and for OCls in particular is growing.

A distinguishing feature of the last two decades is the rapid growth of the number of known open clusters, generally due to IR sky surveys, for example, Two Micron All Sky Survey (2MASS, Skrutskie *et al.* 2006), United Kingdom Infrared Digital Sky Survey (UKIDSS, Lucas *et al.* 2008), Visual and Infrared Survey Telescope for Astronomy Variables in the Via Lactea survey (VISTA-VVV, Minniti *et al.* 2010), and the Wide Field Infrared Survey Explorer (WISE, Wright *et al.* 2010). A large reference list with the discoveries of new clusters can be found in Carraro *et al.* (2016). As a result, the number of known OCls and candidates has increased significantly. The largest modern catalogue of star clusters (Kharchenko *et al.* 2016) contains 3208 objects, the catalogue of optically visible clusters and candidates (Dias *et al.* 2014) contains 2167 objects, and the catalogue of the Sternberg Astronomical Institute contains 168 new open clusters (Glushkova *et al.* 2012).

However these catalogues, accessible as tables, cannot provide all the practical needs for astronomers, because catalogues do not supply their users with a visual information about positions and sizes of star clusters. These catalogues are difficult to use without a visualisation, for example, when someone wants to compile a sample of clusters for investigation with clusters without close neighbour objects, or when someone selects stars from the cluster for investigation and tries to avoid contamination with stars from another cluster. In addition, one can face problems while attempting to identify overdensities on a map of stellar density or on an image of the sky.

Such a situation is illustrated in Figure 1. The upper panel of this figure shows the map of surface stellar density in a square field of about 2.7 degrees centred on the coordinates of star cluster NGC 7788. The map was plotted with the use of a kernel estimator (Seleznev 2016b) and the data from 2MASS (Skrutskie *et al.* 2006) for stars with J<16 magnitudes and with a kernel halfwidth of 5 arcminutes. It is clear that NGC 7788 is in the centre of this map, but what are other overdensities on this map? Of course, one can measure the coordinates of overdensities on the map and look for the known star clusters in the set of catalogues. However, it would be much more useful if we could

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get a graphical presentation of combined table with the cluster coordinates and sizes for the same field. The lower panel of Figure 1 shows the same map with overlapped positions and relative sizes of star clusters from the catalogue of Dias *et al.* (2014). Clusters marked by red have data on their sizes from the star counts of Danilov and Seleznev (1994). It is obvious that if the goal of someone is the study of the stellar content of NGC 7788, it is necessary to take into account the overlapping of projections of NGC 7788 and NGC 7790 on the celestial sphere.

Unfortunately, the existing sites and packages, which visualize the celestial sphere or its parts do not provide the solution to these problems. For example, the WEBDA online database[1] shows the image of the cluster field, but does not indicate the presence of close neighbour clusters and does not allow changes to the image size. A very useful Aladin package[2] has a greater functionality. But even if someone could open the catalogue of Kharchenko *et al.* (2016) in this package, they could not view the sizes of clusters in the sky image.

In addition, there is another problem. The sizes of open clusters are often underestimated in the existing literature, which was shown in Seleznev (2016a). Even if you could open some open cluster catalogues with the Aladin package with indication of cluster sizes, these sizes would be much smaller than the actual ones, as a rule.

The outlined problems can be solved by the new atlas of open star clusters and associations, similar to the old atlas of Alter and Ruprecht (1963), but with the data on newly discovered open clusters, their positions and actual sizes, and with modern technical realization. The atlas of Alter and Ruprecht (1963) contained only about 860 objects, now we have 4 times more clusters.

In this work we propose two realizations of the atlas of OCls. The first realization updates the atlas of Alter and Ruprecht (1963). It is a set of maps, with every map covering a field of 12 by 12 degrees with an overlapping of 2 degrees between adjacent maps. These maps are arranged in three strips along the Galactic equator from −16 to 16 degrees in Galactic latitude (the total number of maps is 108). The second realization is an online atlas. It shows a square field of an arbitrary size either in equatorial coordinates or in galactic coordinates.

The paper is organised as follows. In Sect. 2 we describe the procedure of combining data from the three catalogues mentioned above. Sect. 3 is devoted to the first realization of the atlas (the maps are attached to this paper as a separate pdf file). Sect. 4 describes details of the online version of the atlas and contains brief instructions for the user. Sect. 5 summarises our results and provides some discussion and future prospects for development.

2 The combined table for the atlas

The atlas is based on a combined table, which contains cluster names, equatorial and galactic coordinates of cluster centres, and the cluster radii in arcminutes. To compile our atlas we used the following catalogues:

1. Kharchenko *et al.* (2013),
2. Schmeja *et al.* (2014),
3. Scholz *et al.* (2015),
4. Dias *et al.* (2014),
5. The catalogue of the Sternberg Astronomical Institute, [3], Glushkova *et al.* (2012)

All these catalogues were taken as tables and combined into one table. All coordinates were transformed into degrees and the decimal fraction of degrees. Then this combined table of 5587 rows was sorted in accordance to Right Ascension. The angular radii of clusters were then transformed into arcminutes. In catalogues 1-3 we used the r2 parameter as the angular radius.

At the next step, the rows with duplicated names were deleted. Catalogues 1-3 present the largest number of clusters with the largest number of uniform parameters. Then, we adhered to left rows from these catalogues in the combined table. After the removing of duplicated rows, the table had 3476 rows. After that, different cluster names were checked for cross matches with the help of the WEBDA database. This way we found 26 clusters, presented in the table with different cluster names. In the following, we compared objects in the table with a list of unconfirmed candidates by Kharchenko *et al.* (2013). This list was obtained through the difference between the complete list of MWSC objects (with 3784 rows) and the list of confirmed clusters (with 3006 rows) in Kharchenko *et al.* (2013). This way we removed 159 rows of the combined table, which corresponded to unconfirmed candidates. Finally, the combined table for the atlas consists of 3291 rows.

It is necessary to stress that cross-designation tables in the WEBDA database are very incomplete. There are many cases when one can see objects of different names in exactly the same position in our atlas. It would be

1 http://obswww.unige.ch/webda
2 http://aladin.u-strasbg.fr/
3 http://http://ocl.sai.msu.ru/

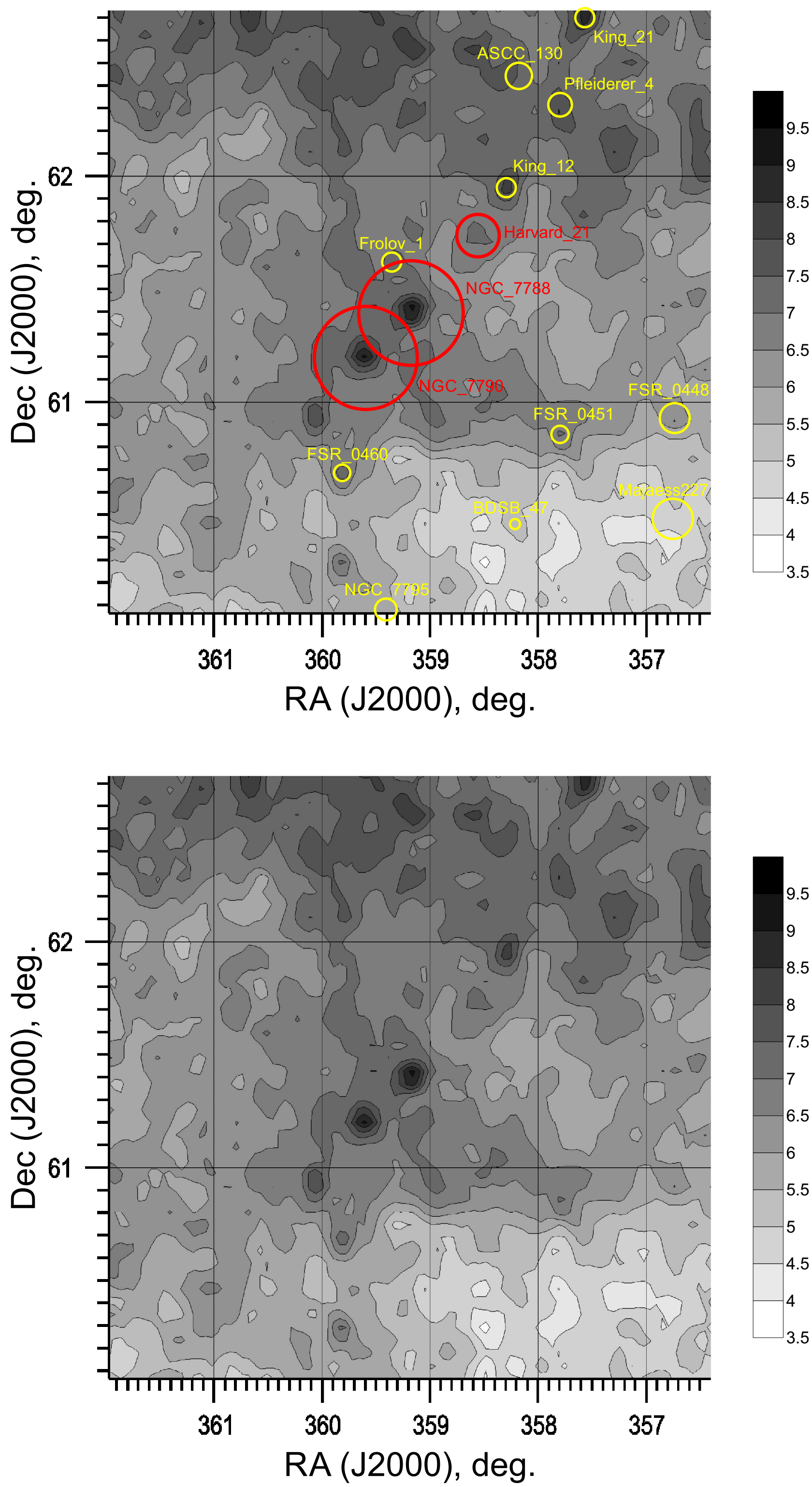

Figure 1. (**Upper panel**) The map of surface stellar density in the field centred on coordinates of star cluster NGC 7788. The map was plotted with the use of a kernel estimator (Seleznev 2016b) and using the data from 2MASS (Skrutskie *et al.* 2006) for stars with J<16 magnitudes and with a kernel halfwidth of 5 arcminutes. (**Lower panel**) The same map with overlapped positions and relative sizes of star clusters from the catalogue of Dias *et al.* (2014). Clusters marked by red have data on their sizes from the star counts of Danilov and Seleznev (1994).

very important to have complete information about cross-identification of different cluster designations, because in some cases different catalogues list different coordinate values for the same cluster. For example, the cluster NGC 6664 has the declination coordinate of −8.21 degrees in the catalogue of Kharchenko *et al.* (2013) and −7.813 degrees in the catalogue of Dias *et al.* (2014). Then, it is quite possible that one cluster would be shown at different positions with different names in the atlas.

The combined table was supplemented by data on cluster radii from Danilov and Seleznev (1994) and from Seleznev (2016a). It has been done because cluster radii in the catalogues listed above are underestimated (Seleznev 2016a).

3 Collection of maps

The atlas of Alter and Ruprecht (1963) contained 36 maps along the Galactic equator with every map covering 12 degrees in the galactic longitude and 40 degrees in the galactic latitude (from −20 to +20 degrees). We have decided to present smaller maps (12 by 12 degrees) but in three strips along the galactic equator with overlapping of 2 degrees between adjacent maps. Then, our atlas consists of 108 maps; 36 maps in the strip between −16 and −4 degrees of the galactic latitude, 36 maps in the strip between −6 and +6 degrees of the galactic latitude, and 36 maps in the strip between +4 and +16 degrees of the galactic latitude. These maps show the positions of 2852 clusters (86.7 percent of the total number in the combined table). 439 clusters have larger galactic latitudes.

Maps have been plotted with the use of the Matplotlib package in the Python language using the vector .svg format. Every map contains a header, which indicates the galactic longitude interval and the galactic latitude interval. Clusters are shown by open circles, the radius of the circle corresponds to the cluster radius in the scale of the map. The name of the cluster is in the nearest vicinity of the circle. In some cases we used arrows in order to make the identification easier. Due to the very close positions of clusters many names overlapped each other and with the circles. Then when it was necessary to edit the maps, it was done manually. The example of the map is shown in Figure 2 for the galactic longitude of $-1 < l < 11$ degrees and the galactic latitude of $-6 < b < 6$ degrees (page 2 of the Atlas).

All maps are stored in the maps.pdf file, attached to this paper. Table 1 shows the list of atlas pages and the galactic longitude and galactic latitude intervals for every page, which makes navigation easier.

This type of atlas is useful for fast surveying of clusters in relatively large fields. It can be efficient for sampling clusters without close neighbours for studying the cluster structure.

4 Web application

In order to identify the known clusters on the density maps or images of the sky, as in Figure 1, one needs to get a map just for the same field, which is covered by their density map or sky image. In order to make such an opportunity possible, we have designed an online application for the atlas. This application plots the map of the square field with an arbitrary size either in equatorial or in galactic coordinates by user request. The user can indicate the cluster name as the field centre, or an arbitrary point in some coordinate system (the equatorial or galactic one).

The combined table with the cluster data was transformed into a database with the use of MySQL, a free database service[4]. It makes data operation easier. Python language supports the use of this database. MySQL package is suitable for the creation of this online resource due to its good safety, the stable operation and its high operation speed. Transformation of coordinates is executed using the Astropy package within Python, and the plotting of the map is performed using Matplotlib package within Python.

The online resource is based on the Django framework[5]. The Django development environment has been chosen because it is a free framework, uses Python as a programming language, has detailed documentation with lots of examples, it can use MySQL as data storage, there are many ready-to-use templates, and it is fast and effective.

The order of the programme operation is the following.

1. The user indicates the centre of the field (by indicating the cluster name or the centre coordinates in the equatorial or galactic coordinate system).
2. The user indicates the size of the field in arcminutes, and the coordinate system they prefer.

4 www.mysql.com
5 www.djangoproject.com

Table 1. The list of atlas pages and its correspondence to the galactic longitude and the galactic latitude intervals.

longitude interval	latitude interval	atlas page	longitude interval	latitude interval	atlas page	longitude interval	latitude interval	atlas page
degrees	degrees		degrees	degrees		degrees	degrees	
359...11	+4..+16	1	119..131	+4..+16	37	239..251	+4..+16	73
359...11	−6...+6	2	119..131	−6...+6	38	239..251	−6...+6	74
359...11	−16...−4	3	119..131	−16...−4	39	239..251	−16...−4	75
9...21	+4..+16	4	129..141	+4..+16	40	249..261	+4..+16	76
9...21	−6...+6	5	129..141	−6...+6	41	249..261	−6...+6	77
9...21	−16...−4	6	129..141	−16...−4	42	249..261	−16...−4	78
19...31	+4..+16	7	139..151	+4..+16	43	259..271	+4..+16	79
19...31	−6...+6	8	139..151	−6...+6	44	259..271	−6...+6	80
19...31	−16...−4	9	139..151	−16...−4	45	259..271	−16...−4	81
29...41	+4..+16	10	149..161	+4..+16	46	269..281	+4..+16	82
29...41	−6...+6	11	149..161	−6...+6	47	269..281	−6...+6	83
29...41	−16...−4	12	149..161	−16...−4	48	269..281	−16...−4	84
39...51	+4..+16	13	159..171	+4..+16	49	279..291	+4..+16	85
39...51	−6...+6	14	159..171	−6...+6	50	279..291	−6...+6	86
39...51	−16...−4	15	159..171	−16...−4	51	279..291	−16...−4	87
49...61	+4..+16	16	169..181	+4..+16	52	289..301	+4..+16	88
49...61	−6...+6	17	169..181	−6...+6	53	289..301	−6...+6	89
49...61	−16...−4	18	169..181	−16...−4	54	289..301	−16...−4	90
59...71	+4..+16	19	179..191	+4..+16	55	299..311	+4..+16	91
59...71	−6...+6	20	179..191	−6...+6	56	299..311	−6...+6	92
59...71	−16...−4	21	179..191	−16...−4	57	299..311	−16...−4	93
69...81	+4..+16	22	189..201	+4..+16	58	309..321	+4..+16	94
69...81	−6...+6	23	189..201	−6...+6	59	309..321	−6...+6	95
69...81	−16...−4	24	189..201	−16...−4	60	309..321	−16...−4	96
79...91	+4..+16	25	199..211	+4..+16	61	319..331	+4..+16	97
79...91	−6...+6	26	199..211	−6...+6	62	319..331	−6...+6	98
79...91	−16...−4	27	199..211	−16...−4	63	319..331	−16...−4	99
89..101	+4..+16	28	209..221	+4..+16	64	329..341	+4..+16	100
89..101	−6...+6	29	209..221	−6...+6	65	329..341	−6...+6	101
89..101	−16...−4	30	209..221	−16...−4	66	329..341	−16...−4	102
99..111	+4..+16	31	219..231	+4..+16	67	339..351	+4..+16	103
99..111	−6...+6	32	219..231	−6...+6	68	339..351	−6...+6	104
99..111	−16...−4	33	219..231	−16...−4	69	339..351	−16...−4	105
109..121	+4..+16	34	229..241	+4..+16	70	349....1	+4..+16	106
109..121	−6...+6	35	229..241	−6...+6	71	349....1	−6...+6	107
109..121	−16...−4	36	229..241	−16...−4	72	349....1	−16...−4	108

3. If the user indicates the cluster name, then the cluster coordinates in the coordinate system indicated by the user are taken as the field centre coordinates.
4. If the user indicates the field centre coordinates in the galactic coordinate system, and wants to get a map in the equatorial coordinate system, the programme transforms coordinates from the galactic to the equatorial system.
5. If the user indicates the field centre coordinates in the equatorial coordinate system, and wants to get a map in the galactic coordinate system, the programme transforms coordinates from the equatorial to the galactic system.
6. Clusters, that fall into the field in accordance with the field size and coordinates of the field centre, are selected from the database and are plotted on the map.
7. The map in the coordinate system indicated by the user is plotted. Clusters are plotted by open circles, with radii taken from the database and plotted in accordance with the map scale. The short cluster name is displayed near the circle.

Cluster names in the combined table and in the database have been shortened in order to optimize the output on the map (to diminish the overlapping of names). Shortened names are listed in Table 2. The user of the

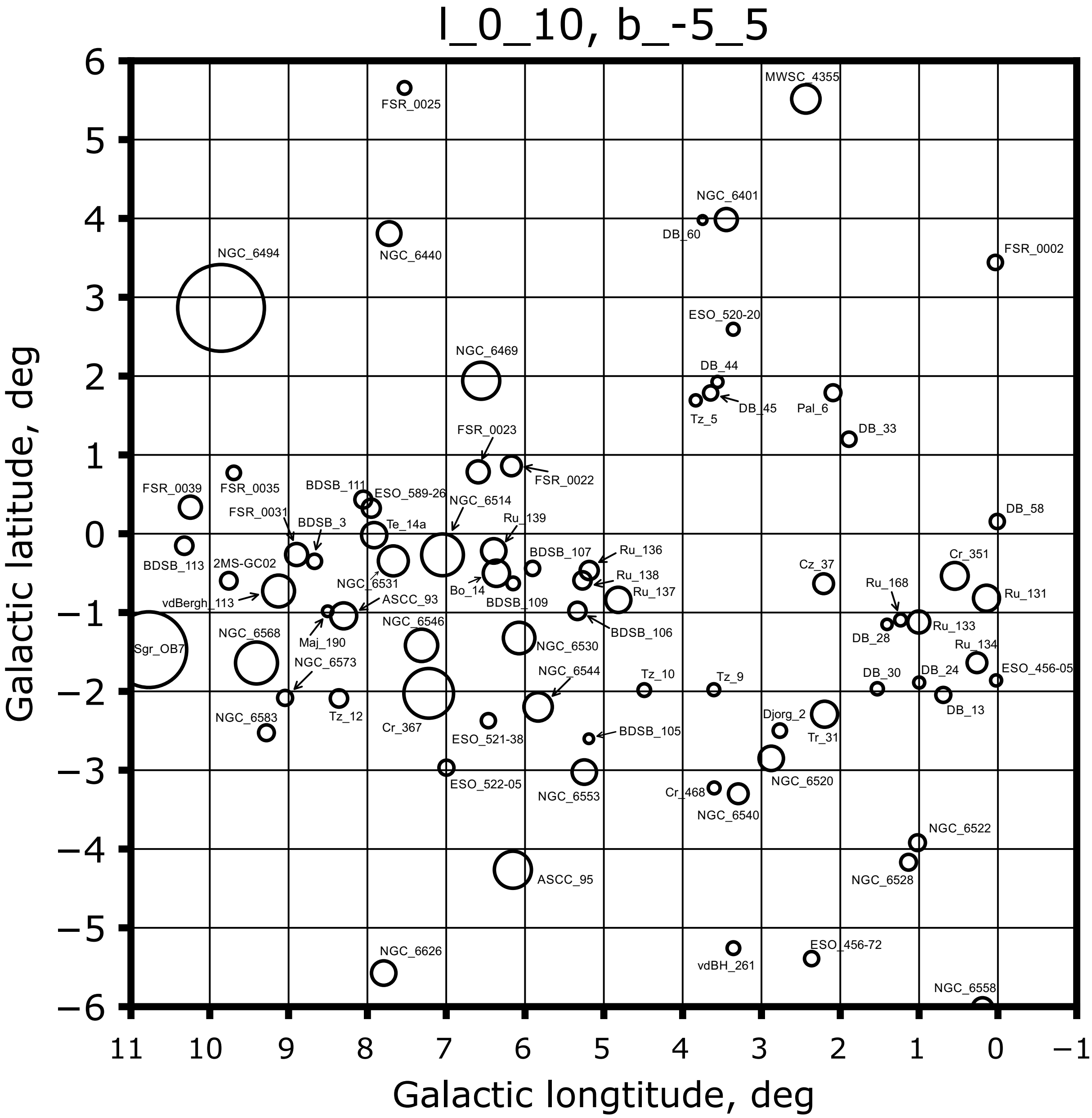

Figure 2. An example of the map for the galactic longitude of −1 < *l* < 11 degrees and the galactic latitude of −6 < *b* < 6 degrees (page 2 of the Atlas). The title in the upper part of the figure designates an interval in galactic longitude (l) and galactic latitude (b).

online atlas should indicate cluster names in accordance with this table. Some shortenings are commonly used, some of them have been adopted by authors of this paper. Other cluster names are the same as in the catalogue of Kharchenko *et al.* (2013). The user of the online atlas should realize that every cluster name contains the underlined symbol between the proper name and the number (for example, NGC_7789; also see Table 2).

This application will work at the following address http://astro.ins.urfu.ru/atlas.

5 Summary and discussion

This paper presents a new version of the atlas of open star clusters. The necessity for a modern atlas has risen due to a sufficient increase in the number of known clusters (by a factor of several) and a lack of possibility to get visual information on the actual positions and sizes of open star clusters with the existing tools used for visualizing the celestial sphere. The new atlas consists of two implementations. The first one is the collection of maps, the second

Table 2. The list of shortenings of cluster names

Name	Short.	Name	Short.	Name	Short.
Alessi_1	Al_1	Juchert-Saloran_1	J-S_1	Ruprecht_148	Ru_148
Barkhatova_1	Bar_1	Kharchenko_1	Kh_1	Saurer_1	Sa_1
Basel_10	Ba_10	Kronberger_18	Kr_18	Schuster_1	Sch_1
Berkeley_58	Be_58	Loden_28	Lo_28	Shorlin_2	Sh_2
Bochum_1	Bo_1	Majaess_1	Maj_1	Stock_18	St_18
Carraro_1	Ca_1	Markarian_50	Mar_50	Terzan_3	Tz_3
Collinder_463	Cr_463	Mayer_1	May_1	Terzan-Ju_20	Tz-Ju_20
Czernik_1	Cz_1	Melotte_20	Mel_20	Teutsch_55	Te_55
Dolidze_12	Do_12	Negueruela_1	Ne_1	Tombaugh_4	Tomb_4
Dutra-Bica_83	DB_83	Palomar_1	Pal_2	Trumpler_2	Tr_2
Feinstein_1	Fe_1	Pfleiderer_3	Pf_3	Turner_12	Tu_12
Frolov_1	Fr_1	Pismis_27	Pi_27	vdBergh-Hagen_19	vdBH_19
Graham_1	Gr_1	Pismis-Moreno_1	Pi-Moreno_1	Westerlund_2	We_2
Harvard_9	Ha_9				

one is the online application. Each implementation serves different tasks.

The collection of maps is useful for fast surveying of clusters in relatively large fields. It can be efficient, for example, for sampling clusters without close neighbours to study the cluster structure. The online application could be very useful for identification of the known clusters on the density maps or images of the sky. The atlas contains available information on cluster sizes, determined by detailed star counts (Danilov and Seleznev 1994, Seleznev 2016a). These cluster sizes are larger, as a rule, than cluster sizes determined with the automated reviews (Seleznev 2016a) and reflect the fact of the existence of vast cluster coronae (Danilov *et al.* 2014).

Further work needs to be done to continue the development of the atlas. Publications with newly found clusters are going on, for example, Loktin and Popova (2017) found 48 new possible candidates. Some objects are shown not to be real clusters after detailed investigations (for example, Pismis 14 in Carraro *et al.* (2017), and ESO131SC09, NGC 5284 and vdBergh-Hagen 164 in Carraro and Seleznev (2012)). It is necessary to find all double mentionings of the same cluster with different names. Maybe, it is worthy to indicate unconfirmed candidates with a different colour (it is possible, that some of them will restore their status in the future). The future Gaia catalogue will cause the number of known clusters to increase, and the revision of the status of many objects.

The authors realize that the terms 'cluster', 'cluster candidate' and 'unconfirmed candidate' are rather relative to some extent. The majority of objects in our atlas are from the catalogue of N.V. Kharchenko and her co-authors (Kharchenko *et al.* 2016). They refer to all these objects as 'clusters', and it is confirmed by their analysis, which includes an analysis of proper motion data (see Kharchenko *et al.* 2016 and references therein). We are following their terminology. However, the data on many of these objects is very few, and the precision of proper motion data is often not high. Consequently, it is possible that the status of many objects in this catalogue could be revised in the future, especially taking into account future high-precision proper motions of Gaia and possible detailed investigations of open clusters by photometry and spectroscopy. The authors plan to follow up on this new available information on the reality of clusters and to take into account this information in future versions of the atlas.

The authors also will continue this work by adding the new available information on open cluster sizes. We hope that the atlas of open star clusters presented in this paper will be a helpful tool for astronomers.

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References

Alter, G., Ruprecht, J. 1963, The system of open star clusters and our galaxy. Atlas of open star clusters (Academic Press, New York, and Publ. House of the Czechoslovak Academy of Sciences, Praha).

Carraro, G., Seleznev, A.F. 2012, MNRAS, 419, 3608-3623.

Carraro, G., de Grijs, R., Elmegreen, B., Stetson, P., Anthony-Twarog, B., Goodwin, S., et al. 2016, Trans. IAU, 29A, 502-521.
Carraro, G., Baume, G., Seleznev, A.F., Costa, E. 2017, Ap&SS, 362, 128, 1-17.
Danilov, V.M., Putkov, S.I., Seleznev, A.F. 2014, Astron. Rep., 58, 906-921.
Danilov, V.M., Seleznev, A.F. 1994, Astron. Astrophys. Trans., 6, 85-155.
Dias, W.S., Alessi, B.S., Moitinho, A., Lepine, J.R.D. 2014, VizieR On-line Data Catalog: B/ocl. Originally published in: 2002, A&A, 389, 871-873.
Glushkova, E.V., Koposov, S.E., Zolotukhin, I.Yu., Yadav, R.S. 2012, In: Moitinho A., Alves J. (Eds), Star Clusters in the Era of Large Surveys, Astrophysics and Space Science Proceedings, Springer-Verlag Berlin Heidelberg, 47.
Kharchenko, N.V., Piskunov, A.E., Röser, S., Schilbach, E., Scholz R.D. 2013, A&A, 558, A53, 1-8.
Kharchenko, N.V., Piskunov, A.E., Röser, S., Schilbach, E., Scholz, R.-D. 2013, VizieR On-line Data Catalog: J/A+A/558/A53. Originally published in: 2013, A&A, 558, A53, 1-8.
Kharchenko, N.V., Piskunov, A.E., Schilbach, E., Röser, S., Scholz, R.-D. 2016, A&A, 585, A101, 1-10.
Loktin, A.V., Popova, M.E. 2017, Astrophys. Bull., 72, 257-265.
Lucas, P.W., Hoare, M.G., Longmore, A., Schröder, A.C., Davis, C.J., Adamson, A., et al. 2008, MNRAS, 391, 136-163.
Minniti, D., Lucas, P.W., Emerson, J.P., Saito, R.K., Hempel, M., Pietrukowicz, P., et al. 2010, New Astron., 15, 433-443.
Schmeja S., Kharchenko N.V., Piskunov A.E., Röser S., Schilbach E., Froebrich D., et al. 2014, A&A, 568, A51, 1-11.
Scholz R.-D., Kharchenko N.V., Piskunov A.E., Röser S., Schilbach E. 2015, A&A, 581, A39, 1-14.
Seleznev, A.F. 2016a, MNRAS, 456, 3757-3773.
Seleznev, A.F. 2016b, Baltic Astron., 25, 267-274.
Skrutskie, M.F., Cutri, R.M., Stiening, R., Weinberg, M.D., Schneider, S., Carpenter, J.M., et al. 2006, AJ, 131, 1163-1183.
Wright, E.L., Eisenhardt, P.R.M., Mainzer, A.K., Ressler, M.E., Cutri, R.M., Jarrett, T., et al. 2010, AJ, 140, 1868-1881.